Obscured star formation in intermediate-density environments

A *Spitzer* study of A901/2 supercluster

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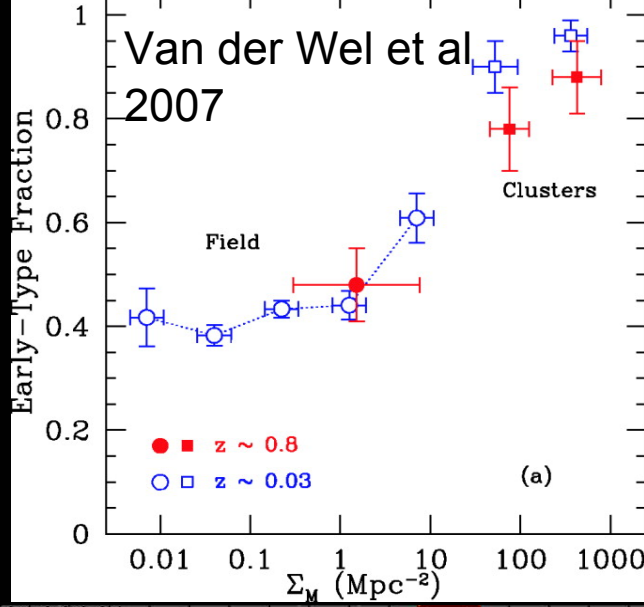
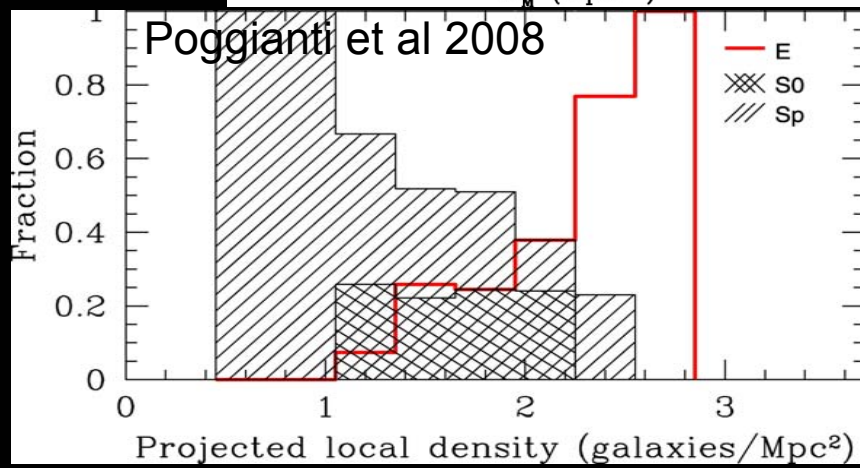
Outline

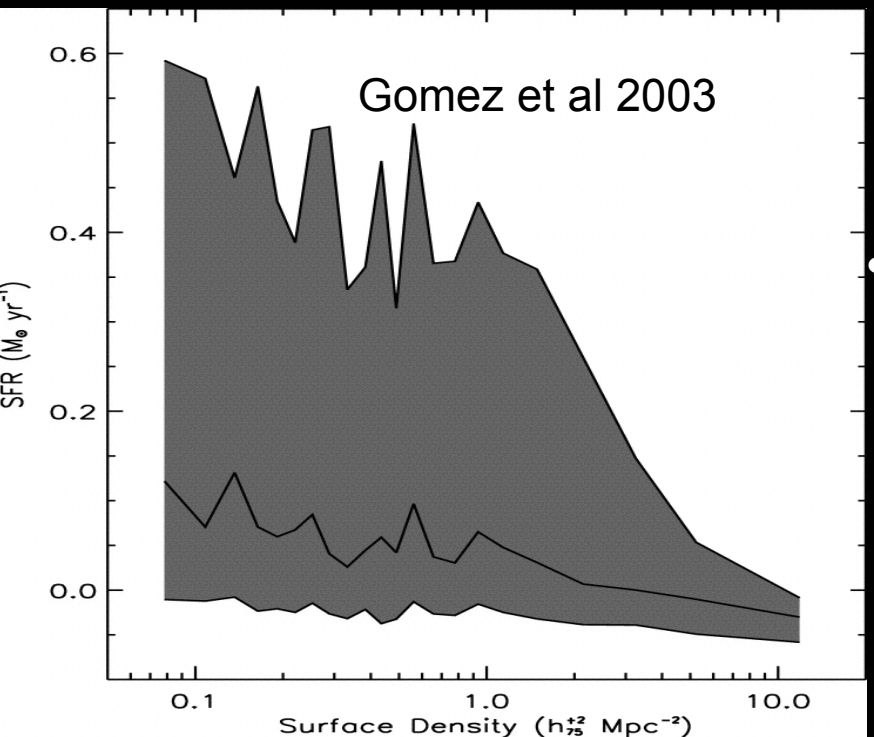
- **Introduction**: what did we know already and what IR data can tell us?
- **Data**: sample and physical quantities
- **Results**:
  - Quantifying importance of red SF galaxies as a function of local density
  - Properties of red SF
- **Conclusions**: possible „transformation“ mechanisms

Known relations

- **Morphology-density** relation (Dressler 1980..)
  - In place since z~1; evolution to z=0 in the sense of an increase in S0s at the expenses of spirals







- **SFR-density** relation (seen in emission lines, color/stellar age)
  - Extends to very low densities
  - No residual morphology-density relation at fixed color (Blanton+05, Wolf+07)
  - Passive spirals: are they really passive?

Mechanisms of interactions

- Interactions with ICM
  - **Ram-pressure**: stripping of cold gas -> fast truncation of SF; may induce burst on front of compression
  - **"strangulation"**: removal of hot gas -> SF is suppressed on longer timescales
- Galaxy-galaxy interactions
  - **Mergers**: trigger SF episodes rapidly exhausted; change in morphology; preferentially at low densities, not cluster cores
  - **"harassment"**: transient burst of SF and change in morphology; preferentially in dense envir. But may induce gas density fluctuations at lower densities

→ ***Net effect is depletion of gas and suppression of SF***

Dust-obscured star formation?

- Environmental interactions may lead to ***temporary enhancement of (dust-obscured and centrally concentrated) SF***, because of gas compression and density fluctuations ⟶ SF may (totally or partially) escape optical detection → *need dust-free SFR indicators*
- **Excess of IR- or radio-bright sources** in nearby and intermediate-z clusters (Smail+09, Miller&Owen2002, Coia+05)
  - ***Different spatial distribution*** wrt to "normal" SF and quiescent galaxies; found in filaments or ***unvirialized clusters*** (Geach+06, Moran+07, Fadda+08, see Bekki's talk); stronger effect at higher z (Marcillac+07, Elbaz+07, Cooper+08, Saintonge+08)
- COMBO-17 (optical) study of A901/2 cluster (z=0.165) reveal an excess of *dusty red galaxies*
  - Similar extinction as BC, ages intermediate between BC and RS, different spatial distribution (Wolf+05,09)

- **What is the importance as a function of environment of star formation "hidden" among red-sequence galaxies (obscured SF?) ?**
- **What is its relevance in the *local Universe* and in systems with *normal to low SFR* (~0.2$M_\odot$/yr) ?**

→ ***dust-free SFR indicators*** *(optical/UV+IR)*

→ ***long environmental density baseline*** *(cluster+field sample)*

image credit: C. Heymans, M. Gray, M. Barden, C. Wolf, K. Meisenheimer, and the STAGES team

A901b

A901a/α

A902

SW group

A901 field: A901/2 cluster complex at z~0.165

- 0.5°x0.5° with ***HST*** F606W (***STAGES***, *see M. Gray's poster*)
- 34'x33' **COMBO-17** (M-H Nicol's poster on COMBO17+4)
- 1°x0.5° with ***Spitzer*** **24μm**
- ***XMM*** 90ks (Gilmour+07)

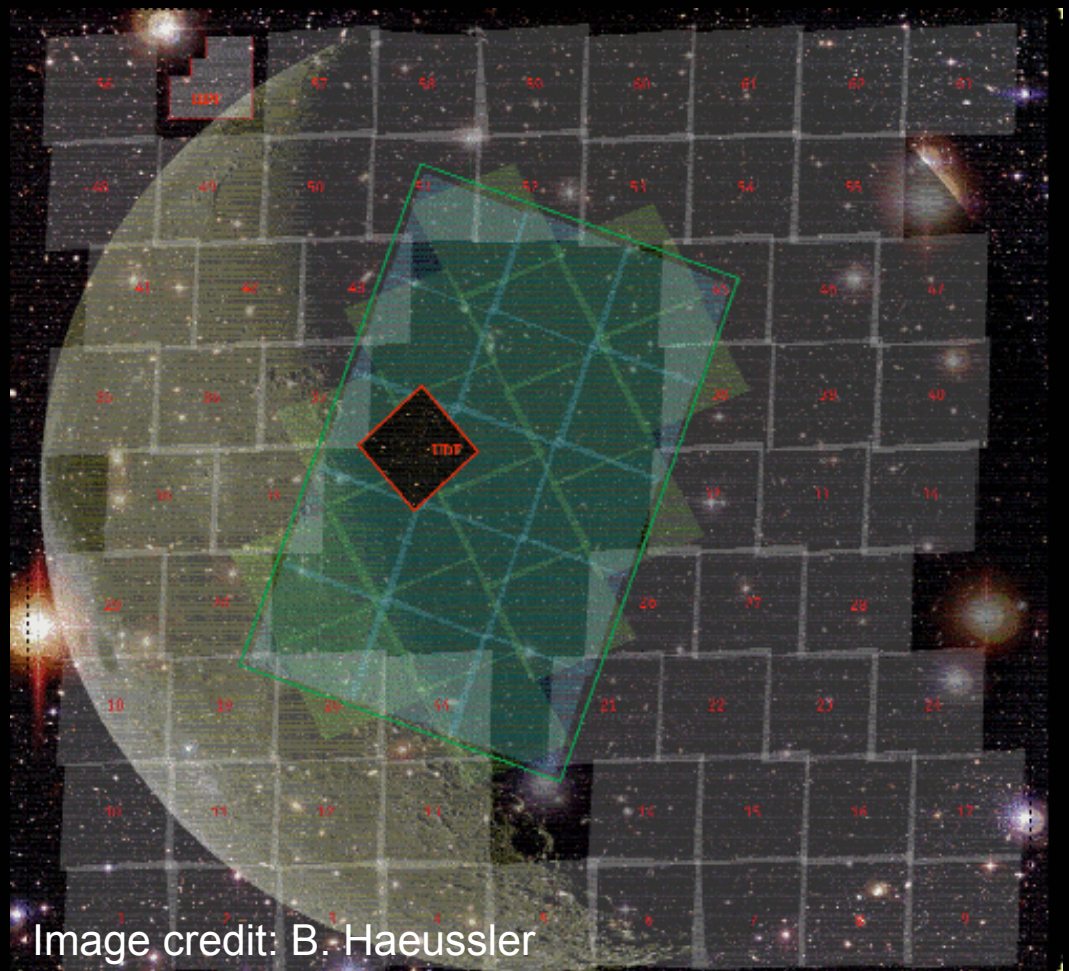


Image credit: B. Haeussler

CDFS: control field sample

- 800 arcmin^2 with ***HST*** F606W F825W (***GEMS***, *see B. Haeussler's poster*)
- 34'x33' **COMBO-17**
- 1°x0.5° with ***Spitzer*** **24μm**
- 1Ms ***Chandra*** catalog (Alexander+03)

The sample

- ***Spitzer*** and **COMBO17** coverage
- **0.05 < z < 0.3**
- M_V<-18
- 1865 galaxies (1390 in A901/2, 475 in CDFS)
  - 600 detections at 24μm (at the 5σ limit of 83μJy)
  - 647 *cluster* galaxies (A901/2 field, 0.155 < z < 0.185)
  - Field sample from CDFS and A901 excluding the redshift range of the cluster

Physical quantities

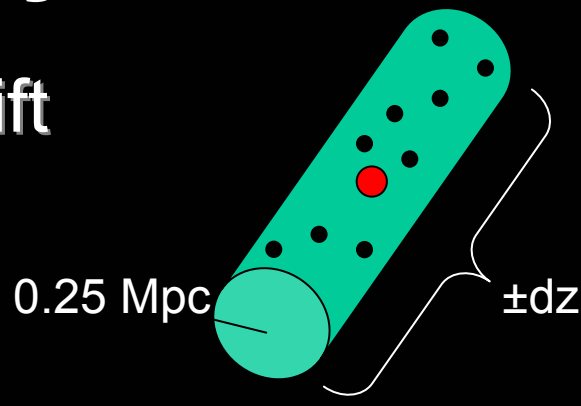
- ***Stellar mass***: COMBO-17 photometry fit to a library of 3 component SFHs based on PEGASE code (Borch et al 2005)
- L_{UV} (1216-3000Å) from flux at 2800Å
- L_{IR} : Sbc template (normal SF galaxy) of Devriendt+99 normalized to the observed 24μm flux; 0.3dex uncertainty from full range of templates
- ***SFR*** = 9.8e-11 ($2.2\ L_{UV} + L_{IR}$) [Bell+05, Kennicutt 98]

Local density

Defined as overdensity wrt average redshift dependent background density

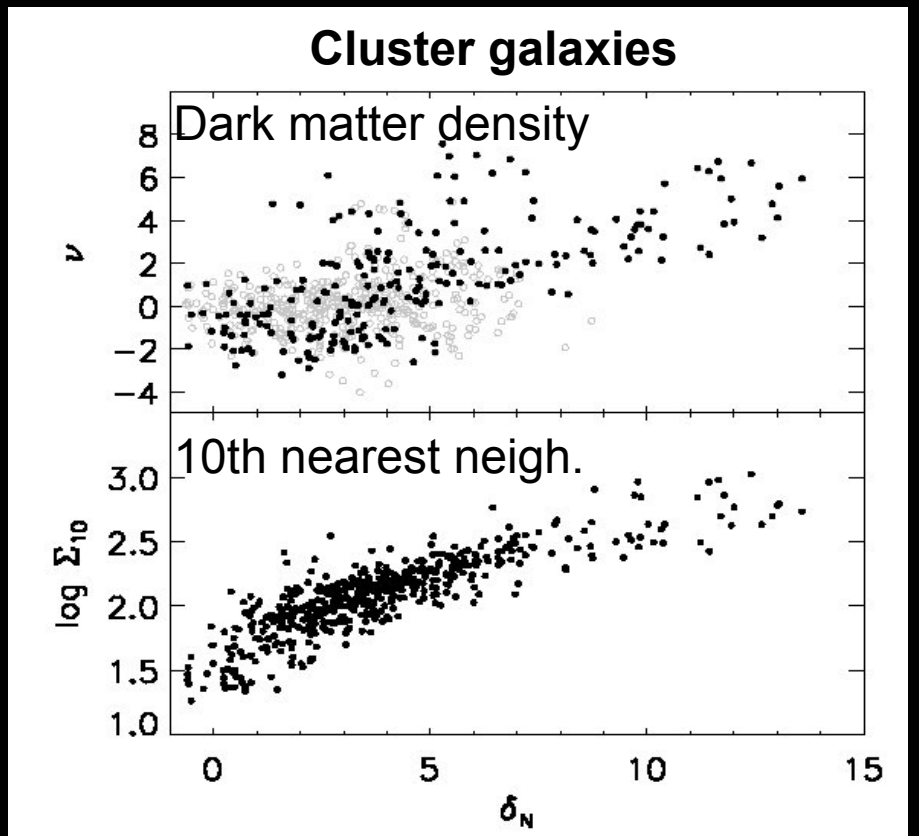
$\delta_N = (\rho_{local} - \rho_{bkg})/\rho_{bkg} = N_{gal}/(V\rho_{bkg}) - 1$

V= cylinder of radius 0.25Mpc and depth set by photo-z error (>0.015)



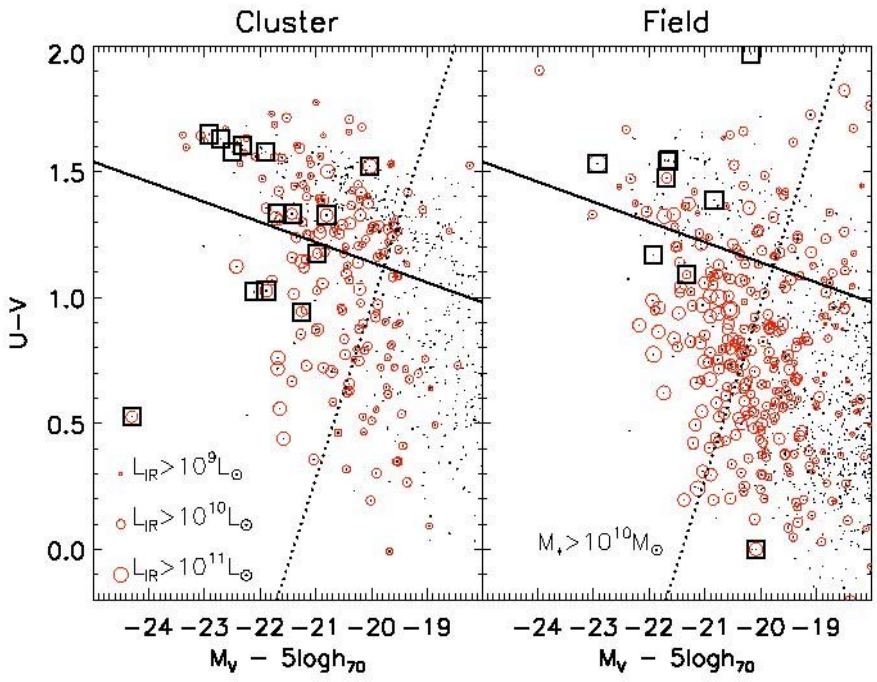
Tested against mock galaxy catalogues (Eelco van Kampen), performs well in ranking galaxy overdensities

Compares well with other indicators of projected density of galaxies and of dark matter



Galaxy Classes

Significant „contamination“ of cluster red-sequence by 24μm emitting galaxies (red circles)
Only few are associated to an X-ray source (squares)

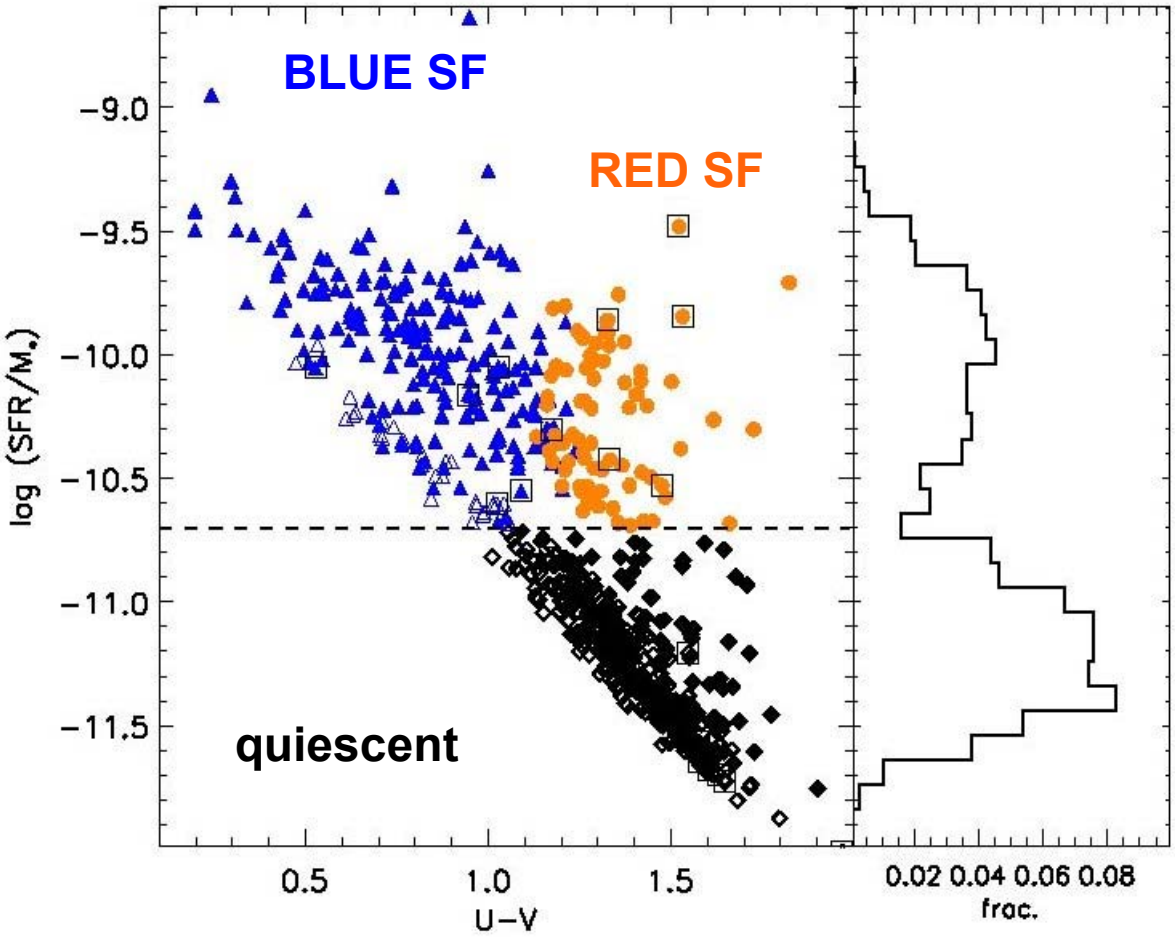


Magnitude-dependent color cut to define RED-SEQUENCE galaxies

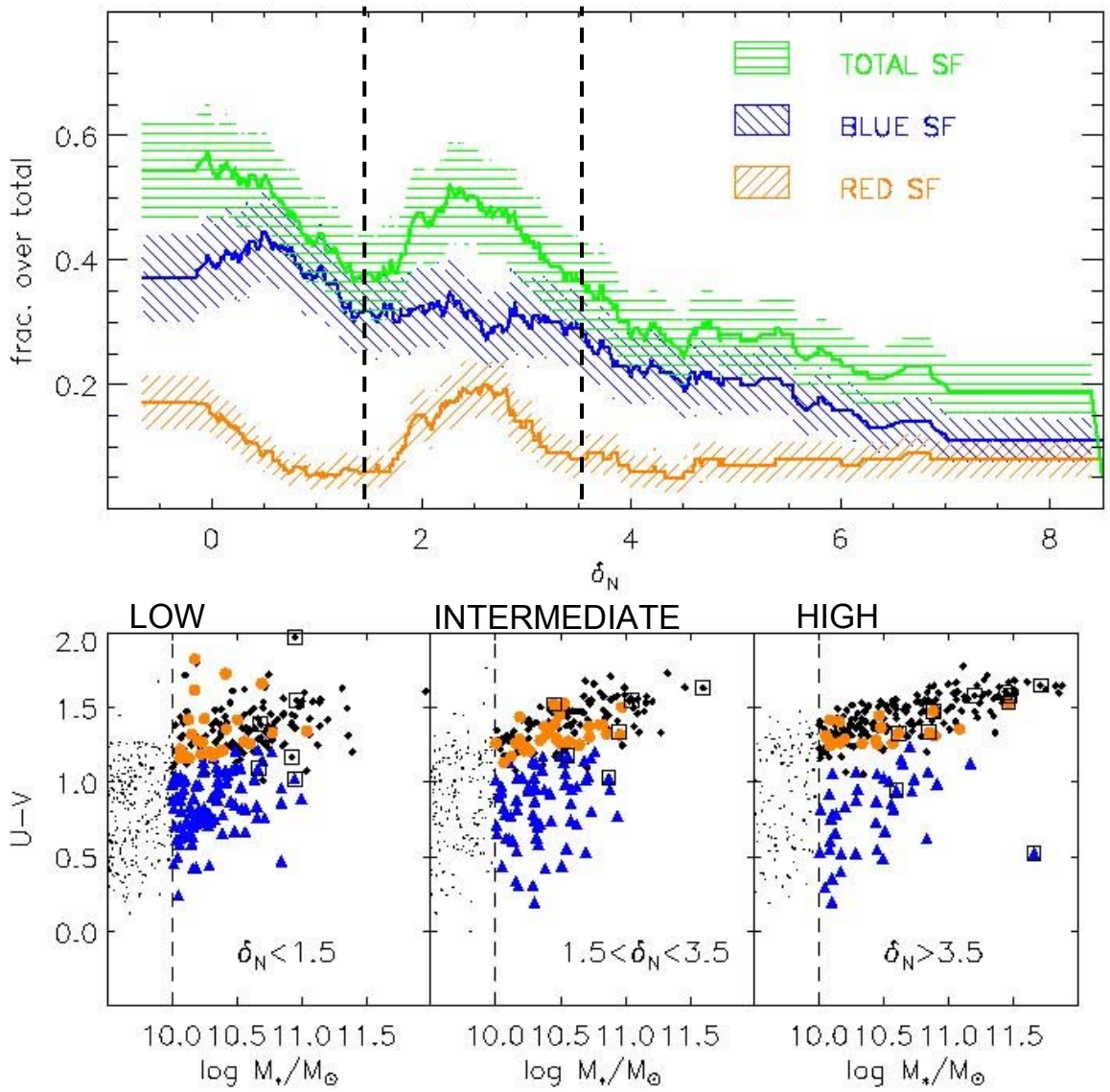
$M_* > 10^{10}\ M_\odot$

log(SFR/M_*)=-10.7
SFR=0.2$M_\odot$/yr at mass limit

Quiescent: ~60% of which 20% IR-det. (filled symbols)
Blue SF: ~30% of which 87% IR-det.
Red SF: ~10% all IR-det



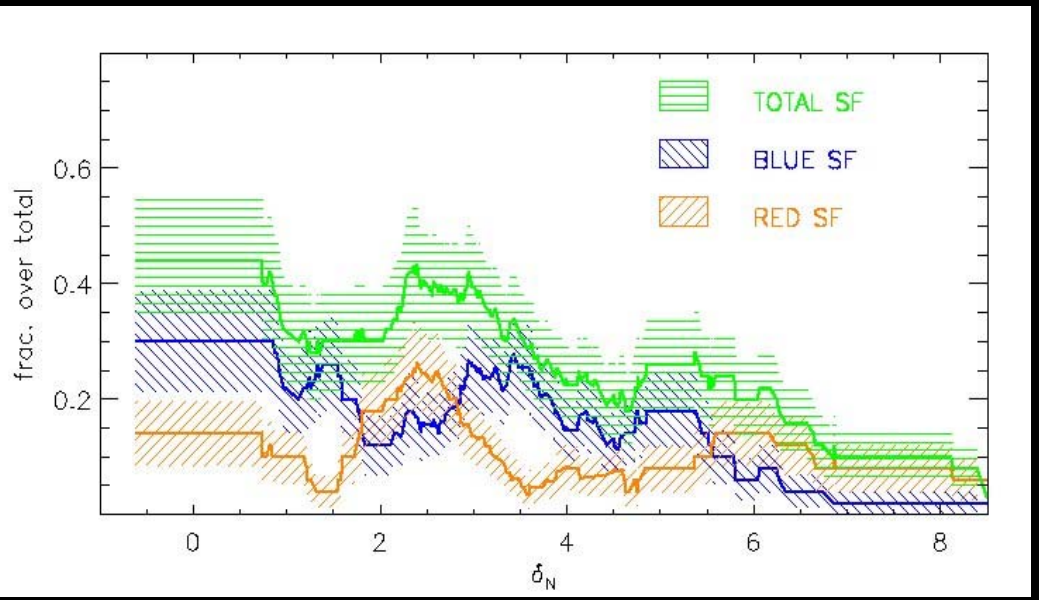
Fractions as function of density



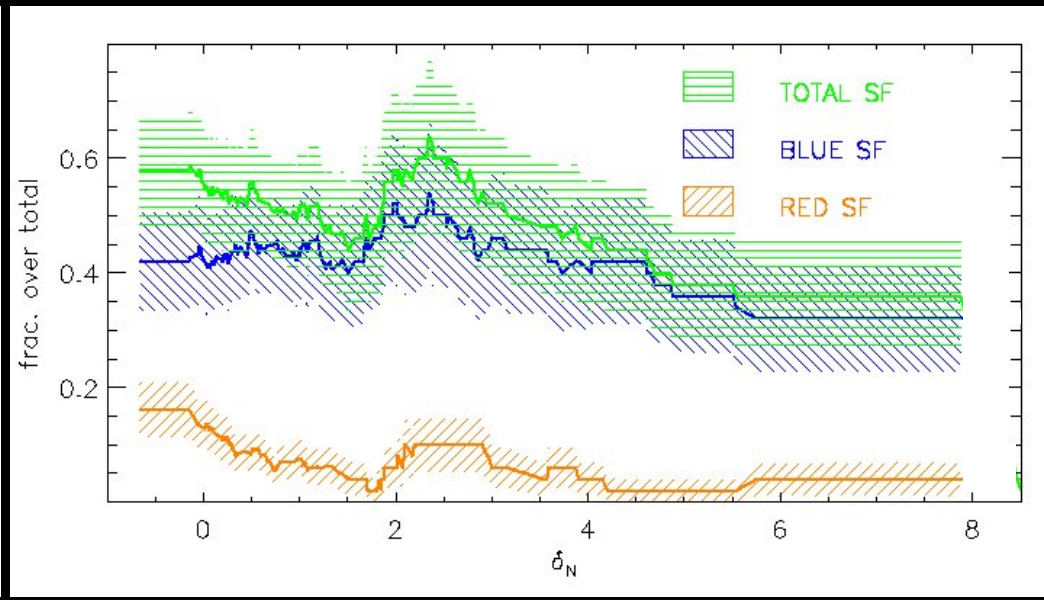
- Overall SF fraction decreases from 60% to 20% at increasing density
- Largely driven by monotonic decrease of blue SF fraction (40% → 10%)
- No monotonic behaviour for **red SF** galaxies → **excess at intermediate density (~20%)**

Cluster versus field

Cluster



Field



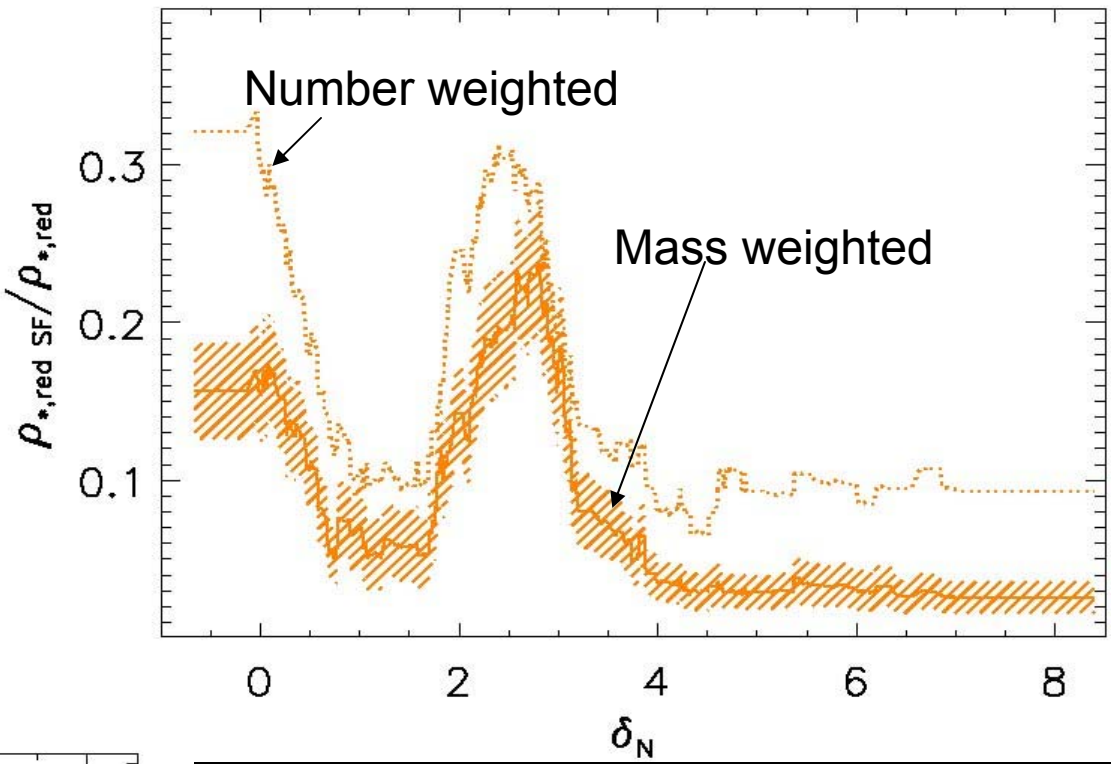
Excess of red SF galaxies is **largely a cluster phenomenon** where their fraction is comparable to that of blue SF galaxies. Only mild enhancement in the field

→ Dependence on both the local and large-scale environment

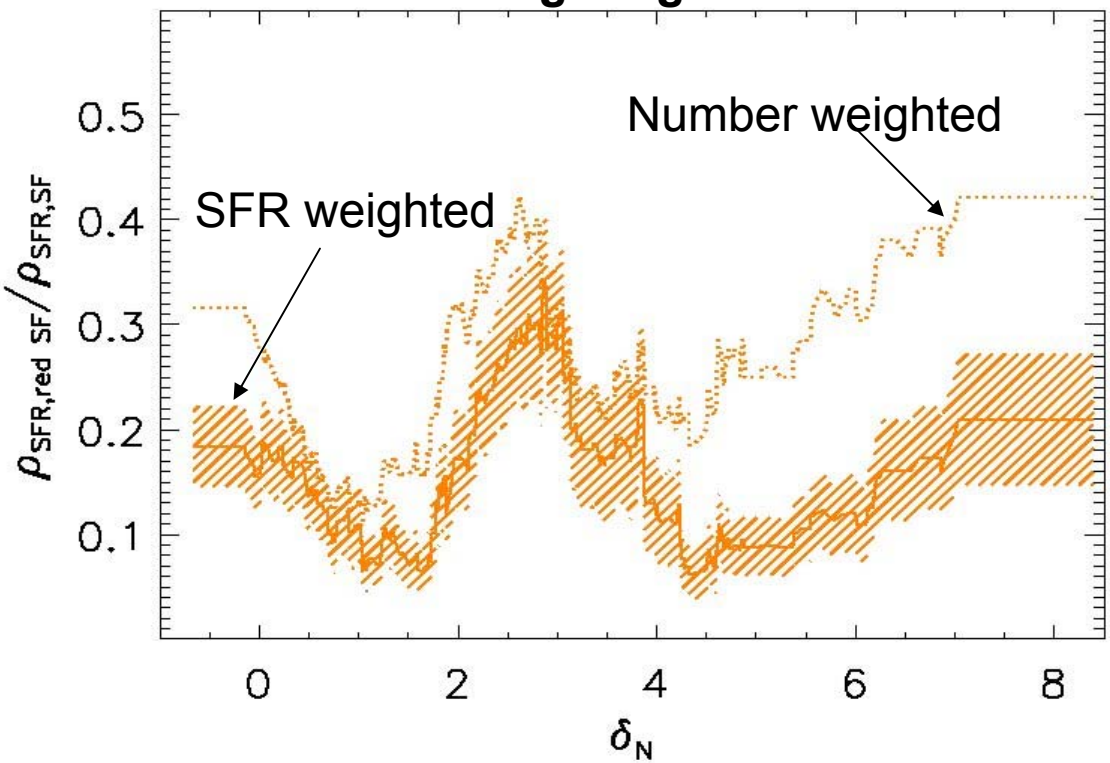
Red SF galaxies contribute ~30% in number and 15% in mass to the red-sequence at low densities (consistent with morph. mix of field RS, Franzetti+07, Cassata+08)

Contamination by SF galaxies on the RS reaches few percent only at the highest densities of the cluster

Fraction among RS galaxies



Fraction among SF galaxies

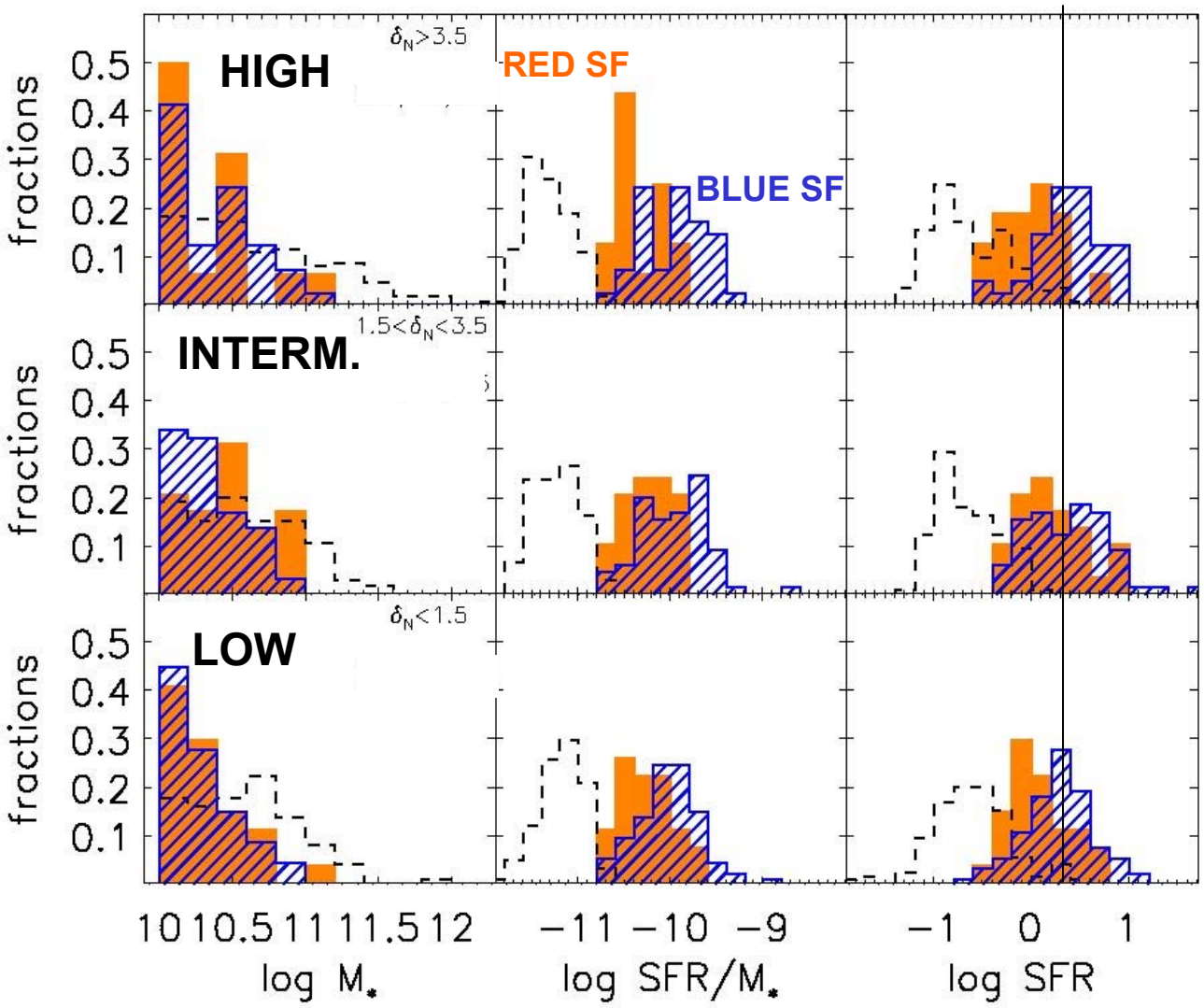


Significant contribution in number and SFR at all densities

At intermediate densities: 30% of total SFR and 40% of all SF galaxies

High densities: lower contribution to SFR than in number → small **suppression of SF in red SF galaxies compared to lower-dens. counterparts**

Properties of red SF galaxies

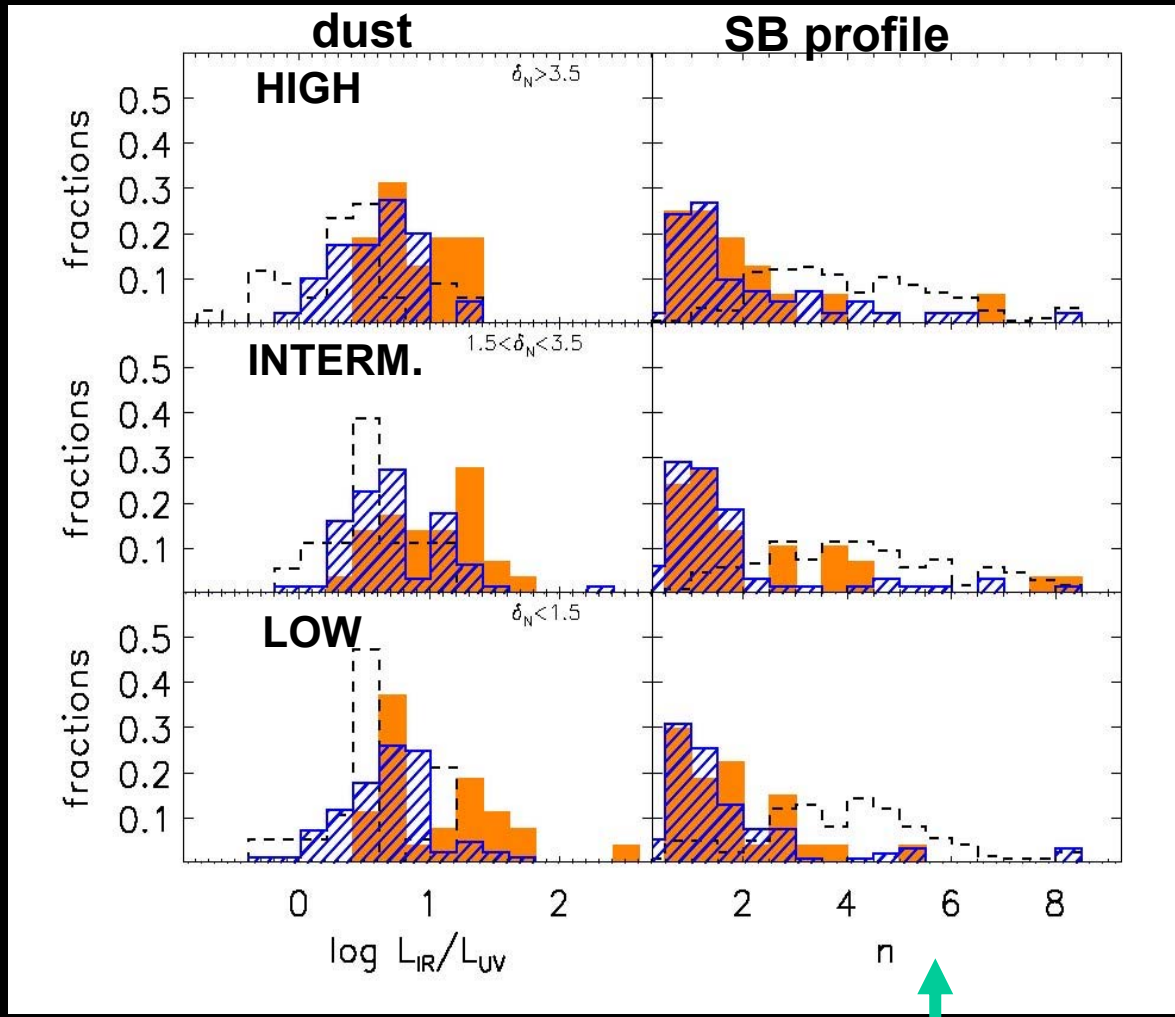


- No evolution with environment in stellar mass of SF galaxies, as opposed to quiescent galaxies

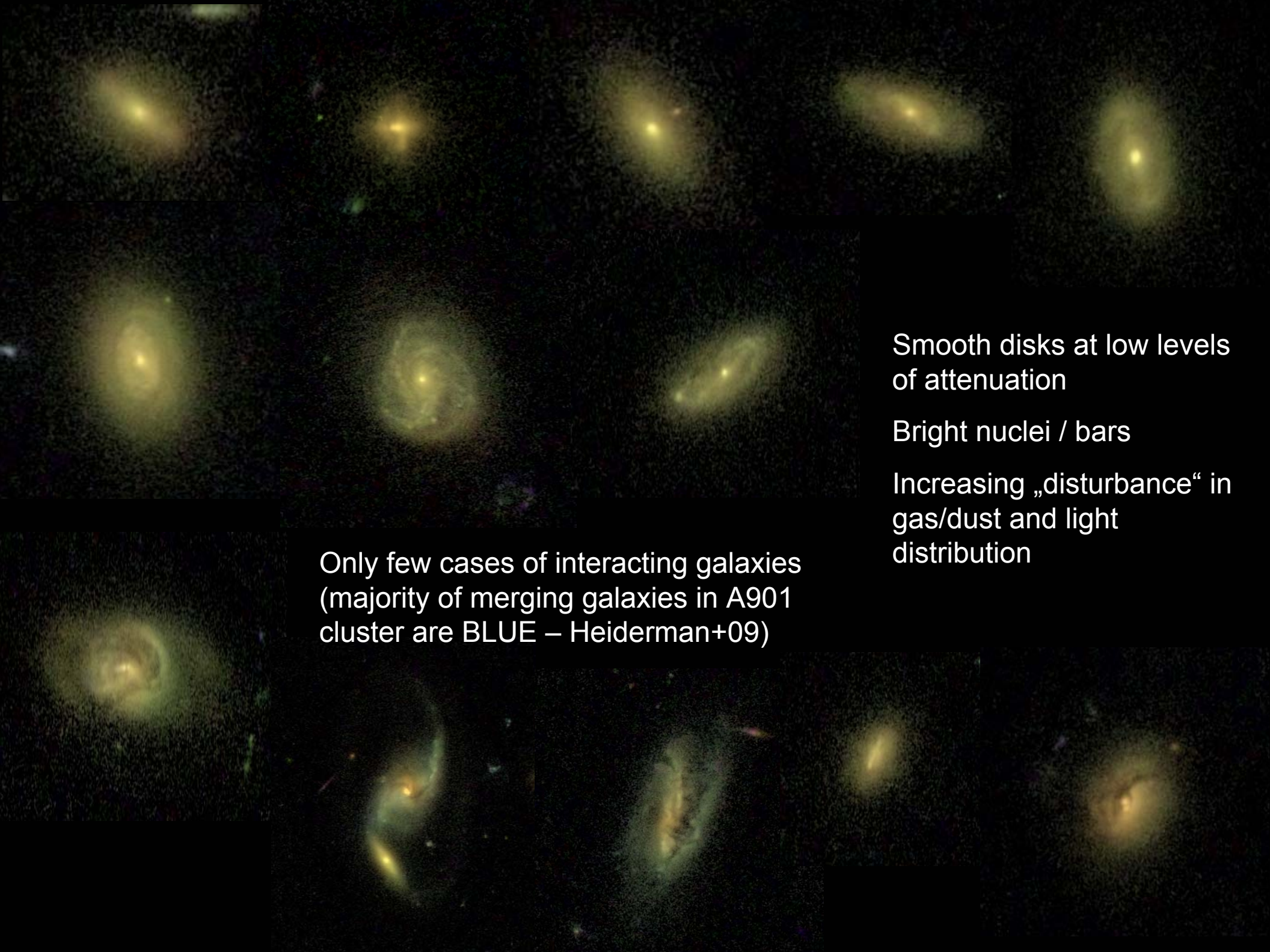
Red SF do not have intense bursts of SF; *their specific SFR is 0.2-0.3dex lower than blue SF galaxies* (cf. Wolf+09: 0.6dex at masses $10^{10.5}$-10^{11} $M_\odot$ including lower SFR systems)

SFR of red SF galaxies is lower at high densities (decrease in SF activity of individual galaxies) → detectable only by including red SF galaxies! (Wolf+09)

Properties of red SF galaxies



- In all environments star formation occurs in disk-dominated galaxies;
- No detectable change in SB profile as function of environment
- No clear difference between blue and red SF



Smooth disks at low levels of attenuation

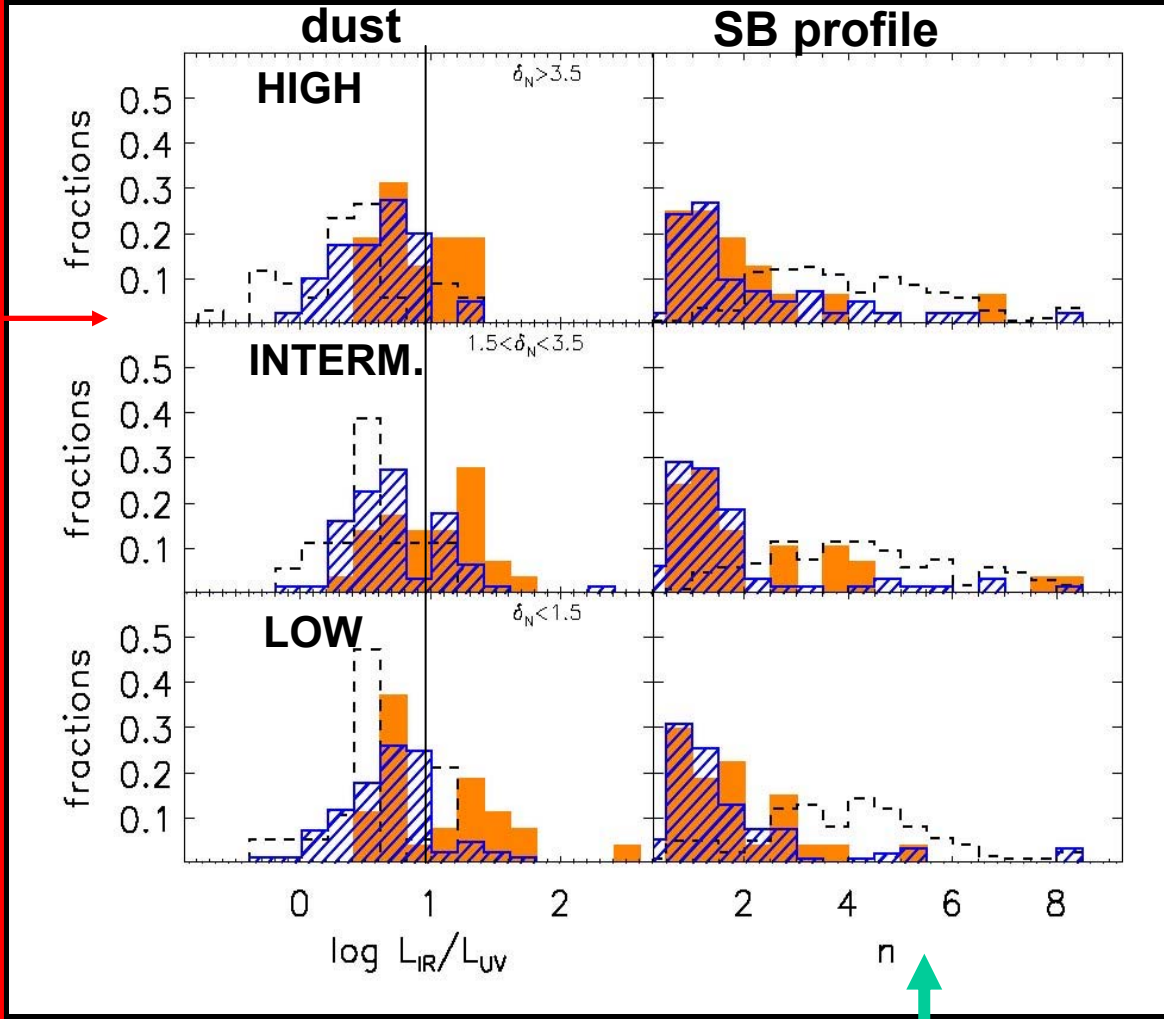
Bright nuclei / bars

Increasing „disturbance“ in gas/dust and light distribution

Only few cases of interacting galaxies (majority of merging galaxies in A901 cluster are BLUE – Heiderman+09)

Properties of red SF galaxies

- *Higher dust attenuation* than blue SF galaxies
- Reduction of the high-attenuation tail at higher densities
- ***Low attenuation*** : low sSFR; high Sersic index (~2.4)
- ***High attenuation*** : higher sSFR (up to 2.5x at low and intermediate dens.); smaller n (~1.5)



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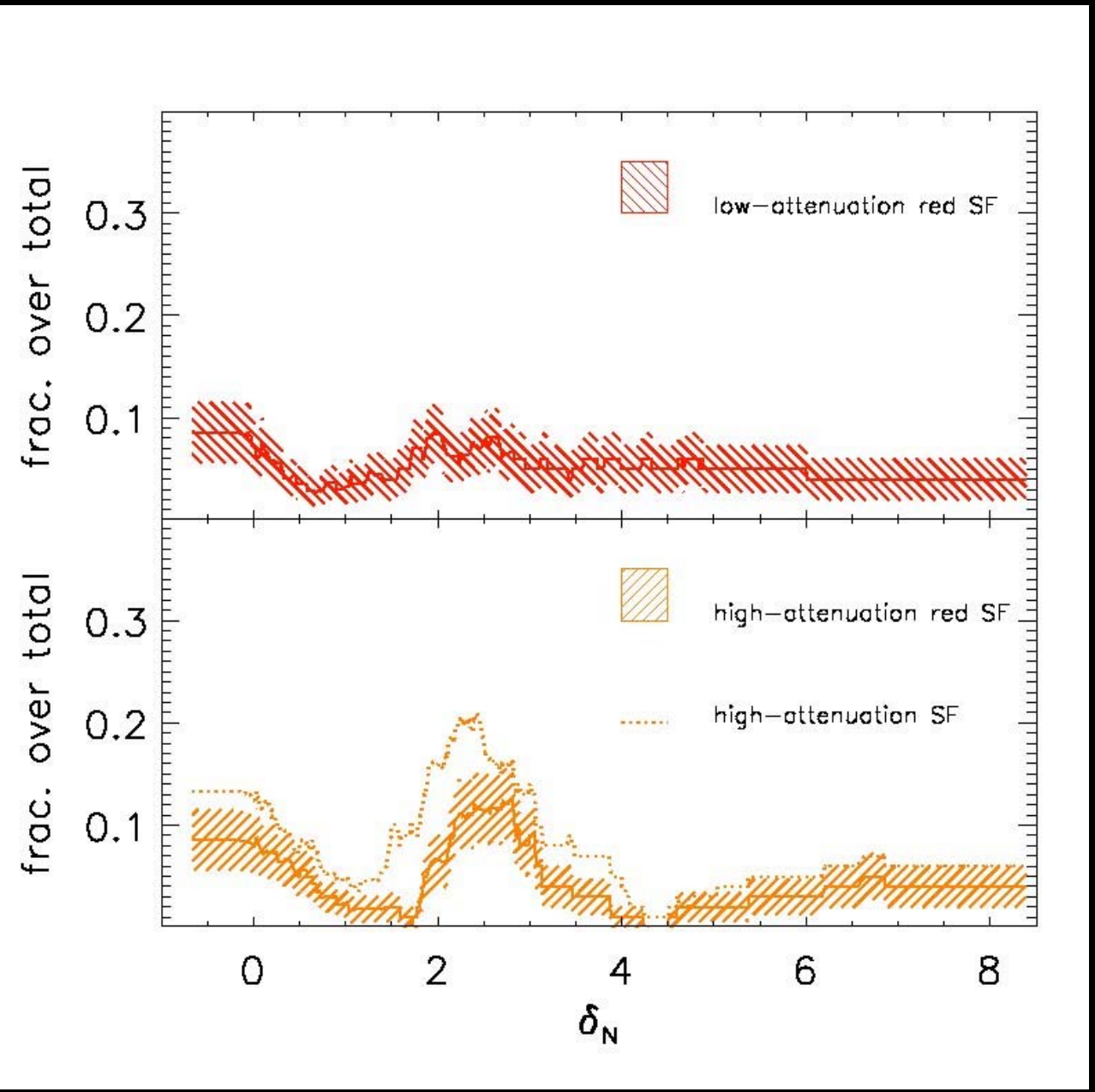


→ no dependence on environment

→ excess of dust-obscured star forming galaxies at intermediate densities (regardless of their optical color)

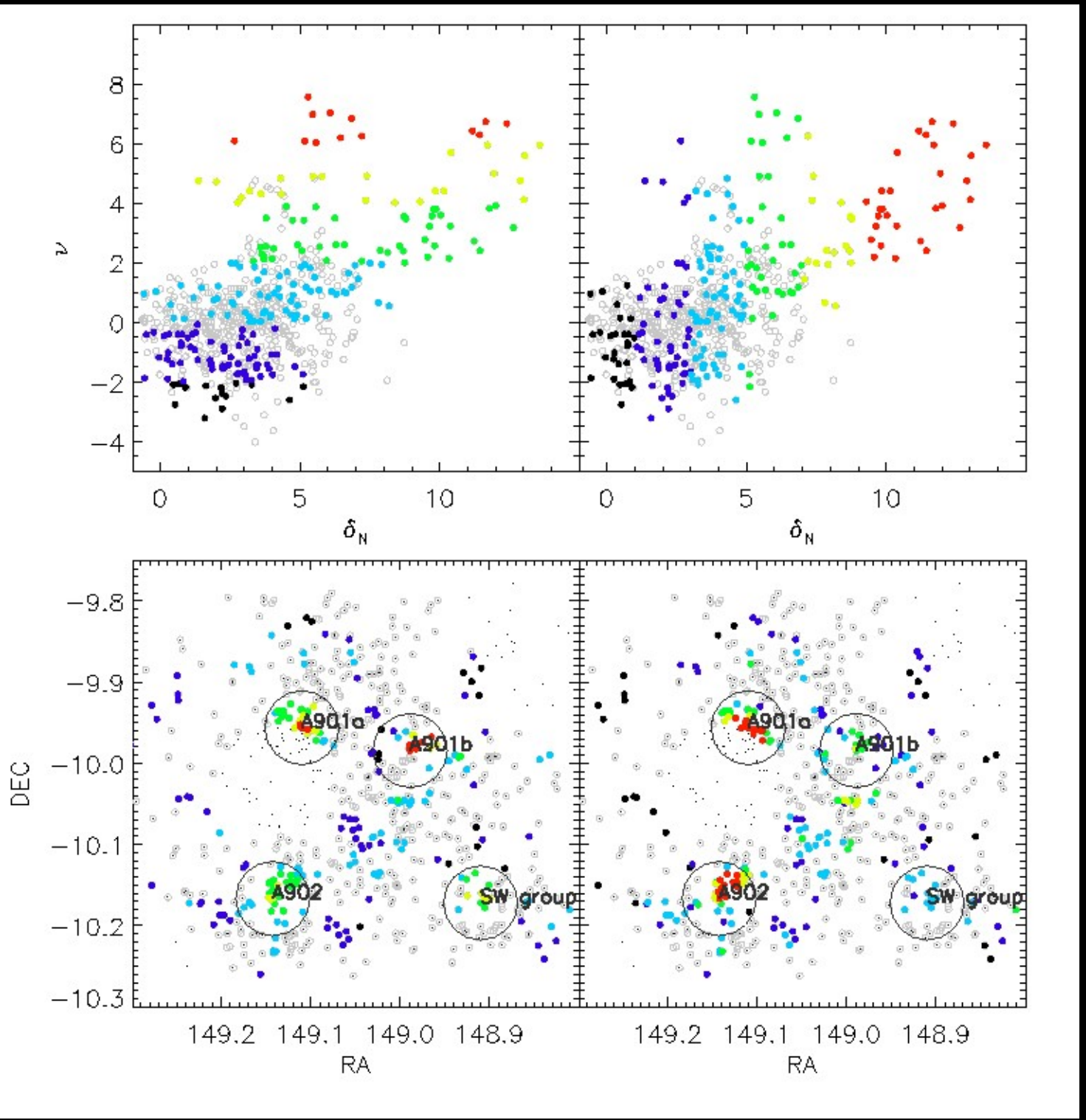
→ excess of red SF galaxies is mainly contributed by truely dusty galaxies

Conclusions I

- Decrease in total fraction of SF galaxies from 60% to 20% with increasing density
- Trend dominated by blue SF galaxies, **but** red SF galaxies show an excess at intermediate densities → 40% of all SF galaxies, 20-30% of total SFR of SF galaxies
  - Recent works find excess of IR-bright galaxies in intermediate-z clusters, preferentially in the outskirts and in unvirialized clusters (Duc+02, Geach+06, Moran+06, Fadda+08,Saintonge+08, Marcillac+07)
- Red SF galaxies are **not starbursting**: SFR similar to blue galaxies, sSFR 0.2-0.3 dex lower; mild decrease in SFR at the highest densities of the cluster
- No change in morphology of SF galaxies with environment nor between blue and red SF galaxies
  - Different timescales of SF quenching and structural changes

Conclusions II

- Two different populations contribute to SF on the red sequence
- **Low-attenuation SF**: low sSFR, relatively high n, no dependence on environment
  - Resemble anemic spirals dominated by old stellar populations with low-level residual SF → suppression of SF via long-timescale process (strangulation?), but *environment not required*
- **High-attenuation SF**: low n, higher sSFR and dust, both possibly decreasing at the highest densities
  - Spirals with bright center or inner bar (centrally-concentrated SF?); only few cases of interacting galaxies
  - *Processes that perturb gas/dust distribution inducing (or sustaining) SF and increasing dust column density, without changing morphology as long as SF is detectable → tidal interactions or harassment at group-like densities?*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